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NAVAL POSTGRADUATE SCHOOL

Monterey, California

MOBILIZING MARINE CORPS OFFICERS

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The ability to rapidly mobilize the Marine Corps in times of crisis is a cornerstone of United States defense strategy. We present a network-optimization based system which, in conjunction with carefully designed and scrupulously maintained manpower databases, assigns Marine officers to mobilization billets. The system is installed on a 386-based personal computer, and takes less than 10 minutes to complete a mobilization involving as many as 40,000 officers (i.e., all available active-duty, reserve and retired Marine officers) and 27,000 billets. The small amount of PC computing time that the system spends on this very large assignment problem includes the production of output suitable for generating orders-to-report via MAILGRAM™. Prior to our work, the only tool the Marine Corps had to help with mobilization assignment was a mainframe-based system which takes two to four days to complete a mobilization. The new system is not only much faster, but it also produces significantly better assignments than the old system with respect to all measures of effectiveness considered.

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MOBILIZING MARINE CORPS OFFICERS

Abstract

The ability to rapidly mobilize the Marine Corps in times of crisis is a cornerstone of United States defense strategy. We present a network-optimization based system which, in conjunction with carefully designed and scrupulously maintained manpower databases, assigns Marine officers to mobilization billets. The system is installed on a 386-based personal computer, and takes less than 10 minutes to complete a mobilization involving as many as 40,000 officers (i.e., all available active-duty, reserve and retired Marine officers) and 27,000 billets. The small amount of PC computing time that the system spends on this very large assignment problem includes the production of output suitable for generating orders-to-report via MAILGRAM™. Prior to our work, the only tool the Marine Corps had to help with mobilization assignment was a mainframe-based system which takes two to four days to complete a mobilization. The new system is not only much faster, but it also produces significantly better assignments than the old system with respect to all measures of effectiveness considered.

"You'll find us rough, sir, but you'll find us ready."

Dickens: **David Copperfield**

MOBILIZING MARINE CORPS OFFICERS

1. Problem Background

Almost all of the United States' contingency plans for responding with force to international crises involve rapid deployment of the Marines in the earliest phases of action. The Marines may be called upon to seize and hold a strategic geographic location or to negate a specific enemy asset. The exact mission will depend on the nature of the crisis, but in any case, it is essential for national security that the Marine Corps be able to mobilize its personnel from peacetime to wartime duties as quickly as possible. This paper considers the problem of providing Marine officers with appropriate duty assignments -- or billets -- during a crisis mobilization.

The Officer Assignment Branch at Marine Corps Headquarters is responsible for providing officers to billets if a mobilization occurs. The branch spends most of its time assigning officers' peacetime billets, but it occasionally engages in mobilization assignment exercises. In these exercises, a hypothetical crisis scenario is assumed and the branch is supposed to go as far as printing (but not sending) **MAILGRAM**™ orders-to-report for officers to fill the required mobilization billets. Afterwards, the branch studies the time it takes to finish the exercise and evaluates the quality of the resulting officer assignments. The branch has concluded from past performances that improvements are needed, for reasons we shall describe.

2. Problem Objectives

The Officer Assignment Branch is responsible for assigning officers to billets both in peacetime and during mobilization. Since the branch spends most of its time on the former and we are concerned here with the latter, it is important to understand the differences between peacetime and mobilization assignment.

First of all, there is a big difference in problem size and urgency. In peacetime, active-duty Marine officers receive new assignments about once every three years; whereas, during mobilization, all active-duty, reserve and retired officers are eligible for immediate reassignment. In the words of the branch chief, mobilization requires "years' worth of work in a matter of days."

Secondly, the peacetime and mobilization assignment problems have different measures of effectiveness. In peacetime, the officer's career development and professional desires are major considerations. Each officer should amass a collection of skills and experiences that enhances the Marine Corps' long-term effectiveness. During mobilization, the Marines' purpose is much more straightforward: just fill the required billets with the best possible officers. In the urgency of mobilization, unlike peacetime, we can ignore officer development considerations. But we must carefully examine the skills an officer currently possesses, and determine how and where they can best be deployed in the present crisis.

We address the officer mobilization problem with an optimization model that combines three objectives:

(1) **Maximize fill**, i.e., maximize the number of billets filled by officers with acceptable (or better) qualifications.

(2) **Maximize fit**, i.e., attempt to fill billets with officers whose qualifications are not merely acceptable but come as close as possible to fitting the billets perfectly.

(3) **Minimize turbulence**, i.e., try as much as possible to keep officers assigned to the same unit that they were assigned to before mobilization, or, failing that, try to have them reassigned to a nearby unit.

Our ability to model and measure these criteria varies. The fill criterion is defined simply as the percentage of billets filled, so it is easily measured. The fit criterion is subjective and requires an approximate model based on several criteria for matching officers to billets, e.g., grade, sex, special training, active-reserve-or-retired status, etc. Turbulence is a lower priority criterion than fit or fill, but is still very important. We define turbulence as the percentage of assigned officers whose mobilization billet requires them to report to a unit more than 100 miles away from their current assignment.

3. Previous Mobilization Methods

Prior to our work, the only tool the Marines had to help with mobilization assignment was the Officer Staffing Goal Model (OSGM) [Decision Science Associates, 1983]. OSGM was designed to provide peacetime staffing targets. There was no intention for OSGM to become a mobilization assignment model when it was created. The Marines relied on OSGM in mobilization exercises for many years, even though it was not designed for this purpose.

The Marines had several reasons for wanting a better mobilization system than OSGM:

(1) **Solution quality**. OSGM focuses on peacetime factors that are irrelevant for mobilization and ignores things that are important, such as turbulence. Optimization with a focus on mobilization issues should produce better solutions.

(2) **Timeliness**. It takes two to four days to complete a mobilization assignment exercise with OSGM, partly because OSGM has to be run on a remote, leased computer. Undoubtedly, the Marines would like to be able to try several model runs before committing to action, but this is difficult with OSGM.

(3) **Cost.** The Marines spend a substantial amount of money on external maintenance and execution of OSGM. Mobilization problems have prohibitive execution cost because they are much larger than the problems OSGM was designed to solve. An in-house model residing on a personal computer is much cheaper and is constantly in reach for data updates.

(4) **Reliability.** A mobilization system must work on the first try.

The Marines asked the Naval Postgraduate School to develop an improved system, first as a masters' thesis (Rapp) and then as a faculty research project (Brown and Rosenthal). We decided to take advantage of the 386-based personal computers that we had recently demonstrated to be capable of large-scale optimization and to exploit the suite of optimization software that was installed in the 80386 environment for this purpose [Bausch and Brown, 1988].

The military has made use of optimization modeling for manpower planning in other instances, e.g., [Gass et al., 1988], [Grinold and Marshall, 1977], [Klingman et al., 1984], [Klingman and Phillips, 1984], [Liang and Buclatin, 1988], and [Liang and Thompson, 1987]. As far as we know, this paper is the first to specifically address officer assignment during mobilization.

4. Data and Terminology

Two files are crucial for our work. The **Wartime Officer Slate File** (WOSF) contains detailed information on every officer. The **Wartime Authorized Strength Report** (WASR) describes every wartime billet for a mobilization scenario. Several versions of WASR are maintained for various war plans. We emphasize that the practical value of a quick-response mobilization system crucially depends upon the Marine Corps's commitment to sustained, in-house maintenance of the WOSF and WASR databases.

Tables 1 and 2 contain lists of the WOSF and WASR data that are required for planning a mobilization. Terminology used in these tables and throughout the paper is explained below.

[- - - - - - Insert Tables 1 and 2 about here - - - - - -]

A **Monitor Command Code** (MCC) is the Marine designation for the unit of a particular officer billet.

A **Military Occupational Specialty** (MOS) is a four-digit code representing an area of expertise that requires specialized qualification and training. Some officers have earned a **primary MOS** (PMOS) plus one or two **additional MOS**'s (AMOS).

A few of the MOS's in WOSF are "catch-all" codes for officers whose specialties are outdated. Similarly, some of the billets do not require special expertise and are coded with an imprecise MOS. We refer to these unspecialized billets as **generalized billets** and the others as **regular billets**. Some generalized billets are partially specialized in that they are restricted to ground officers or aviators.

The **Staffing Priority Level** (SPL) of a wartime billet, in descending priority order, is SPL1, SPL3 or SPL5. (The other SPL's are peacetime priorities.) The higher the billet priority, the more crucial it is to fill the billet with an officer of the right fit.

The grades included in WOSF and WASR are warrant officers through colonels. Generals are omitted because their billets are preassigned.

5. Conceptual Network Model

A network depiction helps to visualize the mobilization problem and strongly suggests a modeling approach. Figure 1 shows a network model in which each officer in WOSF is represented by a node on the left-hand-side and each billet in WASR is represented by a node on the right-hand-side. In this conceptual network, the officer nodes have a supply of one and the billet nodes have a demand equal to the number of officers required.

[- - - - - - Insert Figure 1 about here - - - - - -]

If an officer is eligible for a billet, a directed arc connects the corresponding officer and billet nodes. Eligibility depends on the input data (Tables 1 and 2) and on numerous Marine Corps rules and policies (e.g., no retired officers wanted in combat billets, no grade substitutions wanted in SPL1 billets, etc.). The cost of an arc is a weighted sum of a measure of the quality of the officer-billet fit and the distance between the officer's current MCC and the billet's MCC. More details are given in the Appendix.

There is a high probability that some billets will remain unfilled in any given mobilization because of a shortage of eligible officers. To account for this eventuality, the conceptual network has an extra node, called "clonemaker," that represents a fictitious large supply of officers who can fill any billet at a very high cost. The conceptual model has an arc connecting the "clonemaker" node to all billet nodes.

There is also a very good chance that some officers (particularly retired officers) will not be eligible for any unfilled billets and, hence, will remain unassigned. To account for this possibility, an extra billet node called "unused" is added to the conceptual model, with explicit arcs connecting all officers' nodes to this node. The "clonemaker" and "unused" additions to the conceptual model guarantee network feasibility.

One of us (Rapp) implemented a prototype version of the conceptual model using the NETSOLVE package [Jarvis and Shier, 1988]. This prototype gave encouraging results, but NETSOLVE could handle only a very small number of officers and billets compared to the needs of a real mobilization problem.

Our next implementation of the conceptual model [Rapp, 1987] used the GNET network optimizer [Bradley, Brown and Graves, 1977]. This implementation, dubbed MCMAM, yielded concrete improvement in solution quality over OSGM, e.g., about 6 per cent greater fill. MCMAM did not stand alone, it relied on the Statistical Analysis System [SAS Institute, 1985] for reading, sorting and errorchecking the WOSF and WASR databases. On an IBM 3033-AP mainframe, it took 5 minutes of SAS time and 30 minutes of MCMAM time to generate and solve a 27,000-officer, 10,000-billet problem. We deemed this computational performance inadequate to warrant converting the system to a personal computer or installing it at Marine Corps Headquarters. Accordingly, we engaged in further research to improve performance.

6. Practical Refinements to the Conceptual Model

The conceptual model has some inherent computational impracticalities, so the model we built for the Marines differs from it in a number of important ways. The differences have to do with making the network smaller, reducing the work required to generate it, and reducing the time required to solve it. The key changes to the conceptual model are summarized below:

(1) [**Aggregation**] The number of nodes is substantially reduced by a temporary node aggregation. The MCC's have been mapped into 100 geographic districts. Officers who match one another with respect to grade, sex, limited-duty status, type, occupational specialties and geographic area are merged into a single **officer supply node**. Similarly, billets with matching data attributes are merged into **billet demand nodes**. These aggregations yield three- to five-fold reductions in the number of nodes, yet sacrifice nothing in terms of solution quality.

(2) [**Arc Screening**] A realistic scenario exhibits as many as 40,000 available officers and 25,000 required billets. A literal implementation of the conceptual model would require eligibility tests for 1,000,000,000 officer-

billet pairs. Fortunately, in practice most pairs are ineligible, so we do not have to worry about solving billion-arc networks, but it is vital to be able to pick out the eligible pairs as efficiently as possible. A great deal of effort has been expended in data structure design and programming for the arc generation routine to ensure that most of the ineligible officer-billet pairs are not considered explicitly.

(3) [**Priority Separation**] The problem is separated into subproblems based on billet priority. The first subproblem assigns only the highest priority (SPL1) billets, subject to very tight officer-billet fit restrictions. Subsequent subproblems successively admit lower priority billets and less stringent fit criteria. This approach reflects the preferences of the Marine Corps, and does not detract from our results.

(4) [**Generalized Billet Heuristic**] Because generalized billets have so many eligible officers, they are in reality very easy to fill. Yet, for the same reason, they necessitate the generation of a burdensome number of arcs in the conceptual network. It would be somewhat embarrassing to have to admit that our optimization modeling approach has rendered something easy into

something very burdensome. An appropriate alternative is to treat the generalized billets differently from the regular billets, using a simple greedy heuristic rather than the network optimization model.

(5) [**ENET Solver**] By using an **elastic network** program, ENET, the explicit arcs representing unfilled billets and unused officers in the conceptual model are omitted and handled implicitly. A substantial reduction in the number of arcs results. This is possible because the ENET algorithm treats networks as inequality-constrained linear programs, in which a dynamic subset of the flow conservation constraints are binding at any given iteration. ENET also employs automatic basis aggregation, as described for the XNET variant of GNET in [Bradley, Brown and Graves, 1977, p.28].

The preceding refinements, individually and collectively, result in the generation of much smaller networks than the conceptual model. By use of judiciously chosen data structures, we generate these networks extremely rapidly. The next refinement is an algorithmic device, which might be referred to as a type of linear programming **pricing strategy**, and which greatly reduces network optimization times.

(6) [**Successive Restrictions**] Initially, when solving one of our network subproblems, all the arcs representing perfect officer-to-billet fits are considered eligible, and all other explicit arcs are considered temporarily ineligible. ENET optimizes first over this restricted set. Although the resulting solution is suboptimal in the network at hand, it is found extremely rapidly and furnishes ENET with a good starting point for solving another less restricted version of the original subproblem. In the second restriction, ENET optimizes over all arcs with penalty costs up to one-third the maximum arc penalty cost. ENET then starts from the solution to the second restriction and performs a final optimization in which all arcs are eligible. As you would expect, the perfect arcs are preferred, and large numbers of increasingly imperfect arcs have diminishing influence on the decreasingly restricted solutions. This modest refinement renders between 3- and 20-fold speed improvements.

The computational benefit of all these refinements is documented in Table 3.

[- - - - - - Insert Table 3 about here - - - - - -]

7. Implementation

Application of the preceding ideas leads to an efficient mobilization system. We developed research versions of the system on an IBM 3033-AP mainframe computer under CMS in VS FORTRAN. (See Table 3). We then implemented the system in NDP FORTRAN-386™ [MicroWay, 1988]. (See [Bausch and Brown, 1988] for a complete description of this PC programming environment.) The Marines run the mobilization system on a Compaq™ desktop personal computer with a 25-megahertz 80386 processor, 80387 co-processor and nine megabytes of memory. A run of the system proceeds as follows:

<u>Step 1</u>: [**Data Input and Node Aggregation**] We read three input files: WOSF, WASR and a small file containing policy parameters that define the cost function and the eligibility rules. The WOSF and WASR files are read once and carefully checked for errors. Good records are aggregated and stored in a binary file. Bad records are excluded from the model and reported in exception files. Step 1 takes almost half of the total time of a complete run of the system, but if there are multiple runs (e.g., with different values of the policy parameters), it needs to be performed only once. The binary file contains pointers that are used later for disaggregation.

Step 2: [**Network Generation and Solution for SPL1 Regular Billets**] We generate an elastic network model that is restricted to SPL1 regular billets and the officers who can fill them with no MOS substitution. Then we call ENET as a subroutine and obtain an optimal solution. The optimal assignments are stored on another binary file, while officer availabilities and billet demands are updated accordingly.

Step 3: [**SPL1 Generalized Billet Assignment**] Each SPL1 generalized billet is assigned to the closest available officer of the right grade, subject to sex, limited-duty and air/ground restrictions. These assignments are added to the binary output file and appropriate updates are made.

Step 4: [**SPL3 Subproblem Generation and Solution**] We repeat Steps 2 and 3, for regular and generalized billets, respectively, except now we restrict attention to SPL3 billets and any SPL1 billets that remain unfilled.

Step 5: [**SPL5 Subproblem Generation and Solution**] We repeat Steps 2 and 3, for regular and generalized billets, respectively, except now we consider SPL5 billets and any SPL1 and SPL3 billets that remain unfilled. MOS substitutions are still forbidden on regular billets.

Step 6: [**MOS Substitution Subproblem**] We generate an elastic network model that includes all billets that remain unfilled and all officers who remain unused. The arc generator now allows MOS substitutions on regular billets, subject to the guidelines given in the Appendix. After ENET solves this last subproblem, we produce a summary report on cumulative solution quality (similar to Table 4).

Step 7: [**Node Disaggregation and Solution Reporting**] If the user desires, we create detailed reports on filled and unfilled billets. The optimal assignments are disaggregated to an individual officer-to-billet level, and are placed in a file which can be used as input to a **MAILGRAM**™ printing program.

8. Results

The outputs from many versions of our system have been carefully scrutinized with the view of revealing data deficiencies, modelling oversights and programming errors. Preliminary criticisms have enabled us to identify previously unelucidated institutional policies (a frequent unadvertised benefit of applied operations research).

The final, approved solution exhibits the qualities summarized in Table 4. Total computing time on the Marines' Compaq personal computer is under 10 minutes, with the time divided among tasks as reported in Table 5.

[- - - - - - Insert Tables 4 and 5 about here - - - - - -]

The model run reported in Tables 4 and 5 uses a full-scale Marine mobilization scenario. The same problem could not be run on the old system used for mobilization, OSGM, because of its large size, but we have compared results on smaller problems. In every case, the new system achieves better quality solutions with respect to every measure of effectiveness considered.

9. Conclusions

United States' defense plans rely upon our ability to mobilize the Marine Corps on extremely short notice. The Marines have invested heavily in prepositioning strategic stockpiles of ammunition and equipment to prepare for contingent crises. But without getting the people to the stockpiles in time, in the worst situation, our prepositioned assets could be captured by an enemy and used against us. Therefore, the problem we have addressed in this paper is one of great significance to our national defense. With the system we have described and a firm commitment to maintaining the WOSF and WASR databases, the Marine Corps is ready to quickly mobilize its officers in war.

Appendix: Guidelines for Assignment Eligibility and Cost

Our mobilization system uses the following Marine Corps policies and preferences to decide whether an assignment arc should exist between particular officer/billet pairs, and to decide how much existing arcs should cost. A non-retired officer who matches a billet perfectly with respect to grade, MOS, MCC, sex and limited-duty status costs zero to assign. All other allowable assignments have positive cost.

- Active-duty officers are preferred to reserve officers for some SPL1 billets.

- Active-duty and reserve officers are preferred to retired officers in SPL1 billets and, to a lesser extent, in SPL3 billets.

- Females and limited-duty officers can never be assigned to billets from which they are restricted.

- Grade substitution is much more undesirable in SPL1 billets than in SPL3 or SPL5 (with the exception of some warrant officers who can fill lieutenant billets).

- Grade substitutions are permissible in SPL3 and SPL5 regular billets under the following guidelines:

    - Any officer can be assigned a billet that is one grade above his grade.

    - An active-duty aviation officer, a reserve officer and a retired officer can be assigned a billet that is one grade below.

    - A retired officer can be assigned a billet that is two grades below.

- Grade substitutions are permissible in SPL5 generalized billets under the preceding guidelines.

- Grade substitutions are prohibited when MOS substitutions take place.

- In technical billets, MOS substitutions are worse than grade substitutions. In non-technical billets, the reverse is true.

- It is preferable to assign an officer to a billet requiring his PMOS rather than one of his AMOSs.

- MOS substitution is permissible only for certain specified MOS pairs.

- Billets in certain specified MCCs, which are involved in the earliest mobilization actions, have the highest priority.

- Some reserve officers carry "hip-pocket orders" to report to specific MCCs in case of emergency. These officers should be assigned billets in the specified MCC.

- SPL1 billets should not be assigned to officers more than a specified number of miles away. SPL3 billets have a similar, but less stringent, restriction.

- Officers who are enrolled in the early weeks of certain basic MOS schools should not be given mobilization assignments. (They are screened out in the WOSF input step.)

- Retired officers cannot be used unless they retired less than a specified number of years ago. (This is also screened in the WOSF input step.)

Several of these guidelines require specification of policy parameters. Our mobilization system stores default values in a small file which the user can edit at any time.

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Officer Supply Data

Source: Wartime Officer Slate File (WOSF)
For each officer:
- (a) Social security number
- (b) Grade
- (c) Current Monitor Command Code (MCC)
- (d) Primary Military Occupational Specialty (PMOS)
- (e) First additional MOS (AMOS1)
- (f) Second additional MOS (AMOS2)
- (g) Officer type: regular, reserve or retired
- (h) Sex
- (i) LDO (limited duty officer) status

Table 1: The Wartime Officer Slate File (WOSF) is a database that contains current records on all active, reserve and retired Marine officers. Our mobilization system uses WOSF as input and extracts the listed attributes for all officers who are eligible for mobilization. Officers with matching attributes are temporarily aggregated into "officer supply nodes" for a network optimization model. The WOSF contains as many as 40,000 eligible officers, from whom aggregation yields about 10,000 to 15,000 supply nodes.

Billet Demand Data

Source: Wartime Authorized Strength Report (WASR)
For each billet:
- (a) Staffing Priority Level (SPL)
- (b) Monitor Command Code (MCC)
- (c) Grade
- (d) Required MOS
- (e) Number of officers needed
- (f) Female officer allowed (yes or no)
- (g) Limited duty officer allowed (yes or no)

Table 2: The Wartime Authorized Strength Report (WASR) is a Marine Corps file that contains every required wartime billet for a specific mobilization scenario. The Marines maintain several versions of WASR for different war plans. Our system reads the listed billet attributes, maps the billet locations into geographic areas, and then temporarily aggregates matching billets into "billet demand nodes." A WASR file can contain as many as 25,000 billets, which are typically reduced about three-fold by aggregation.

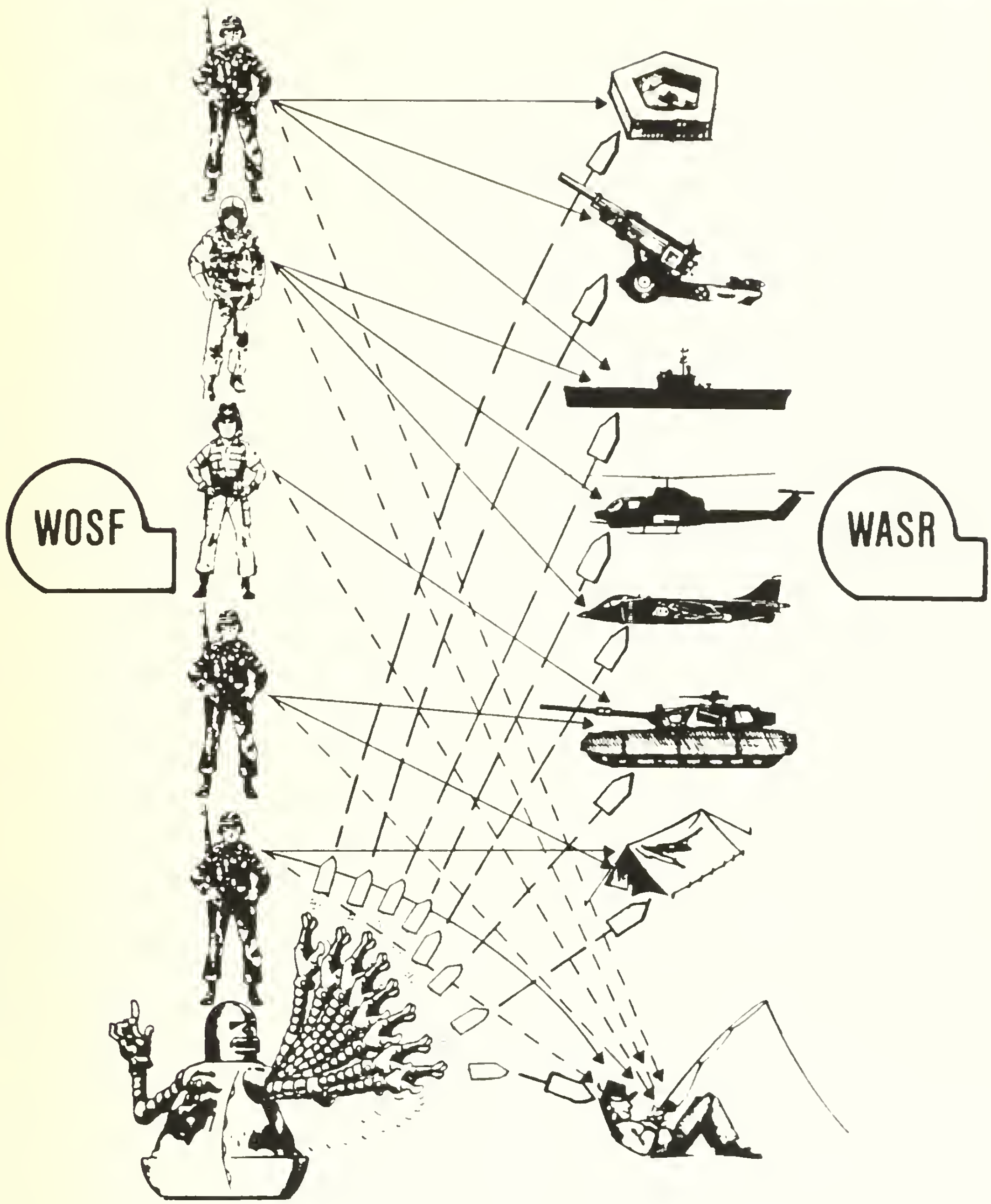

Figure 1. A conceptual network model of the Marine Corps mobilization problem depicts each officer as a supply node and each billet as a demand node. The "clonemaker" node at the lower left accounts for the possibility that some billets will remain unfilled due to a shortage of eligible officers. Conversely, the "unused" node at the lower right accounts for available officers who are not eligible for any unfilled billets. A literal implementation of the conceptual model would be computationally impractical, so our mobilization system employs several important refinements.

Effect of Refinements on Network Computation Time

Problem size:
27,003 officers
10,441 billets

Version Date	Refinements Added	Mainframe CPU Minutes Generation	Optimization
9/87	Node aggregation Priority separation Arc screening	10	20
11/87	Generalized billet heuristic	3	
	ENET solver		0.5
4/88	Specialized data structures	0.02	
	Successive restrictions		0.12

Table 3: Our refinements to the conceptual model were added in stages in research versions of the mobilization system. This table documents cumulative improvements in the network solution time for one (SPL1) subproblem. The research versions of the system were implemented on an IBM 3033-AP mainframe, whereas the version currently used by the Marines resides on a personal computer.

Solution Quality

	Officer Mobilization Assignments			
	------ Priority ------			
	SPL1	SPL3	SPL5	TOTAL
Number of billets	13,625	12,186	938	26,749
Percentage of billets filled	94.9	91.1	94.0	93.2
Percentage of filled billets in which assignment uses:				
- perfect grade fit	84.4	79.6	91.3	82.4
- perfect MOS fit	92.8	87.6	72.0	89.7
- no turbulence	58.3	42.0	14.5	49.3
- active-duty officers	65.9	50.9	19.3	57.4
- reserve officers	19.6	25.1	9.9	21.8
- retired officers	9.4	15.1	64.9	14.0

Table 4: The Marines are concerned about several measures of effectiveness in officer mobilization. The primary objective is to maximize the number of billets filled with suitably qualified officers. The second objective is to maximize the quality of officer-to-billet fit. Fit is evaluated with respect to several criteria, including grade fit, MOS (military occupational specialty) fit, and preference for active-duty officers and reserves over retired officers. The third objective is to minimize turbulence, defined as the percentage of assigned officers whose mobilization billet requires them to report to a unit more than 100 miles away from their current assignment. Results of our mobilization system for a full-scale Marine mobilization scenario are reported. This example is too large to run on the Marines' old system; but, on smaller problems where comparisons could be made, the new system always produced significantly better results with respect to all measures of effectiveness.

Computing Effort as Percentage of Total Time

Data input and node aggregation		48%
Network generation	}	
Network optimization	}	33%
Generalized billet assignments	}	
Node disaggregation and report writing		19%
		100%

Table 5: Our mobilization system provides the Marines with sufficiently rapid response to be used in wartime. On a personal computer, it takes under 10 minutes for full-scale Marine Corps mobilization, with computational effort distributed as above. Network generation and solution effort is accumulated over several subproblems, the largest of which has 21,000 nodes and 120,000 arcs.

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